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# Energy efficiency of rubberized asphalt concrete under low-temperature conditions

Murat Karacasua[a,*], Arzu Er[b], Volkan Okur[a]

[a]Eskisehir Osmangazi University, Department of Civil Engineering 26480, Eskisehir, Turkey
[b]Akdeniz University, Department of Civil Engineering, 07356, Antalya, Turkey

**Abstract**

Crumb tire rubber mixed asphalt concrete has a wide applicable area in road construction such as high energy absorbers and thermal stabilizator. Rubber's high damping capacity allows consideration of rubber modified asphalt mixtures as part of a damping system to decrease vibration therefore improving the comfort and durability of the pavement. Rubber particles may also help from cooling off asphalt concrete during transportation from plant to the site. Heat loss of asphalt concrete during transportation is one of the major problems in road construction. The slow rate of heat loss of the rubber mixed asphalt concrete enables the mixtures to be produced even in cold weather conditions. Moreover, since rubber absorbs UV rays from the sun, ice forming on the roadways could be reduced in the cold weather regions. To study the insulation effects of tire rubber on asphalt concrete Marshall Stability tests were carried out in laboratory using different amounts and type of crumb tire rubber on different temperatures. Applicability and effectiveness of final product were tested on site. From the results of the tests in laboratory and site it is concluded that with the appropriate type and amount of rubber it is possible to reduce heat loss of asphalt concrete. Insulation decreases the amount of energy required to replace heat losses, thereby reducing energy costs. Rubber can also help reduce heat produced during production on site. This can provide cost effective and energy efficient solutions and maintain environmental sustainability.



*Keywords:* Rubberized asphalt concrete, Marshall Stability, Heat Loss.

* Corresponding author. Tel.: +090 222 239 3750; fax: +90 222 239 3752.
*E-mail address*: muratk@ogu.edu.tr.

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## 1. Introduction

The highway transport system carries over 95 percent of passenger transport and over 90 percent of the surface transport of goods in Turkey. The country's road network is extensive, with over 600.000 kilometers of roads. By the end of 2011, 62.930 kilometers of this network consisted of motorways, and a total of 59.473 kilometers was paved. The government has made strenuous efforts to extend and improve its road network, especially in the building of additional motorways. The economic crisis of 1998 and the earthquakes of 1999 caused some of these projects to be postponed, but they, and others, are expected to go ahead. Accordingly the asphalt production in Turkey is given in Fig.1. As seen in Fig 1 there is a continuous increase in demand for asphalt pavements (Tunc, 2007).

During the design process of asphalt pavements different environmental and traffic loading conditions should taken into account. It should be able to resist such external factors and as well as climatic conditions without being damaged. On the other hand even designed to top specifications sometimes asphalt pavements do not provide acceptable, safe and sound usability due to early deterioration. In general most of the deterioration is due to top-down cracking or rutting. There are several reasons for the deterioration to occur. One of the most plausible causes would be the heat loss during the transportation of asphalt concrete to the site. In general it is difficult to maintain the compaction quality if the internal heat of asphalt concrete is below 160$^{o}$C. One of the attempts in this context is to use polymer based additives such as Styrene–butadiene–styrene (SBS), styrene–butadiene rubber (SBR). SBS is a synthetic hard rubber copolymer that's used for things where durability is important and often substituted in part for natural rubber based on the comparative raw materials cost. It's a type of copolymer called a block copolymer in which the backbone chain is made up of three segments. The first is a long chain of polystyrene, the middle is a long chain of polybutadiene, and the last segment is another long section of polystyrene. The molecular structure of SBS may be linear or radial, and styrene blocks bond to form uniformly distributed domains, leading to the creation of a physically cross coupled system. (Bates and Fredrickson 1999).

The features of polymer modified asphalts (PMA) are more vividly witnessed as an increase in elastic response, viscosity, cohesion and thermal stability. Choubane et al. (1999) published the findings from a ten-year study of asphalt-rubber surface mixtures and concluded that crumb rubber increased ride ratings and reduced surface rutting. Regarding to the base material, the addition of crumb rubber to asphalt decreases thermal instability, permanent deformation and increases resistance to low-temperature cracking. (Choubane et al., 1999; Cano and Charania, 1989; Heerkens and Von Meier, 1989; Esch, 1982). Despite considerable research in this area, PMA have still not been comprehensively characterized, due to the complex nature and interaction of the asphalt and polymers. This paper presents a study on the polymer effect of recycled tire rubber on static and dynamic characteristics of rubber modified asphalt concrete.

## 2. Experimental Programme

### *2.1. Materials*

Appropriate aggregate gradation for hot-mix bitumen was designed according to technical specification of General Directorate of Turkish Highways, (GDTH) 2006. The aggregates have a mean grain size (D50) between 0.30-3.0 mm and a coefficient of uniformity (Cu) between 2.0-3.0. The boundaries of the GDTH and the prepared grading curves were given in Fig 2. The physical properties of the aggregates were given in Table 1

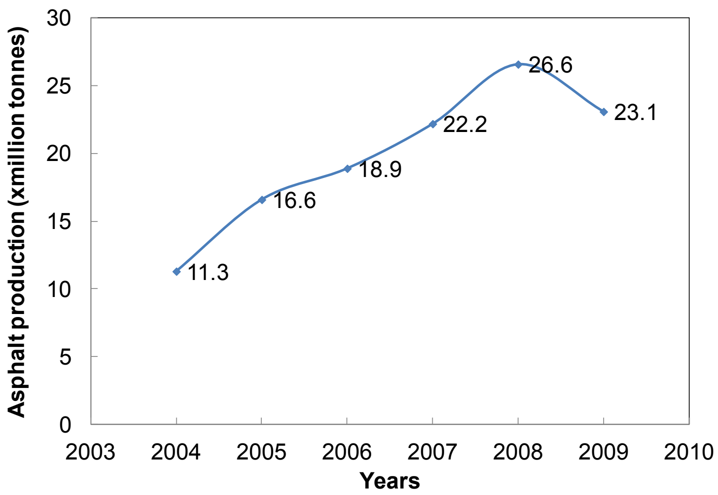


Fig. 1. Variation of asphalt production in Turkey

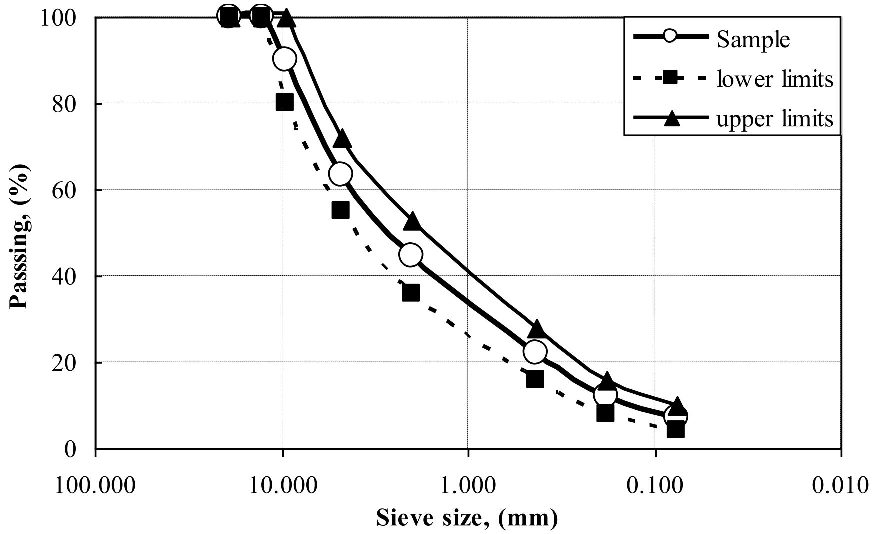


Fig. 2 Gradation curve of the aggregates used in the study

## *2.2. Test Results*

The asphalt used for the mixture was obtained from the TUPRAS (IZMIT) refinery plants. Table 2 shows physical properties of virgin binder. Tests were conducted with 50-70% penetration value. Bitumen was modified by product of tire rubber commercially named CMR-300 and SMR-400(Granulated tire rubber obtained by shredding and grinding the tire after removing of the fabric and steel belts and passes #40 mesh). Picture and SEM image of CMR-300 are given in Fig. 2. Rubber contents of 10 and 15% by weight of bitumen were blended with bitumen for each type at a mixing temperature of about 160 $^{o}$C (Chen and Lin 2005). To verify the repeatability of the result of the tests, three samples are prepared by way of an identical procedure (premixing the rubber with bitumen using a mixer at 500 rpm for 2 h) from each mix.

Table 1 The physical properties of aggregates used in tests

| Properties | Test Values | Standards |
|---|---|---|
| Specific gravity of coarse aggregate, 25 $^{o}$C, gr/cm$^{3}$ | 2.65 | ASTM C127-07 |
| Water absorption of coarse aggregate, % | 0.24 | ASTM C127-07 |
| Specific gravity of fine aggregate, 25 $^{o}$C, gr/cm$^{3}$ | 2.631 | ASTM C128-07a |
| Water absorption of fine aggregate, % | 1.08 | ASTM C128-07a |
| Specific gravity of filler, 25 $^{o}$C, gr/cm$^{3}$ | 2.73 | ASTM C128-07a |
| Los Angeles wearing test , % | 28.90 | ASTM C535-09 |
| Freezing and thawing test, % | 5.48 | ASTM C1646-08a |
| Bitumen absorption, % | 0.14 | ASTM D4469-01 |

Table 2. Physical properties for 50-70% penetration

| Properties | Test results |
|---|---|
| Penetration, (25$^{0}$C, 1/10 mm) | 6.35 |
| Specific Gravity, (g/cm$^{3}$) | 1.03 |
| Softening Point, ($^{0}$C) | 47 |
| Heating Loss, (%) | 0.60 |
| Flaming Point, ($^{0}$C) | 267 |
| Ductility, (25$^{0}$C, 5 cm/min) | >100 |

Fig 3 Picture and SEM image of CMR-300

Air voids, practical unit weight, Marshall stability and bitumen filled void ratio has been evaluated. The optimum rubber contents obtained for mix design in which CMR-300 10% and SMR-400 15%.

Due to space limitations only the results of Marshal Tests are given for control and CMR-300 sample in Fig 4 and Fig. 5 respectively.

The proper asphalt ratio was determined as 4.4% by taking the average according to these for the variables in Table 3 by using Figure 5.

One of the important features of the CMR-300 and SMR-400 additive is the fact that the mixture heat drop to the same temperature of control sample for about ten minutes later. Fig. 6 shows the variation of heat loss without aggregates just for virgin binder and rubber additives. The test results for mix design is shown in Fig. 7 where it may be seen the heat loss curve is similar in shape to that Fig. 6.It may also be seen that heat of SMR-400 mixture is cooled more slowly compared to CMR-300.

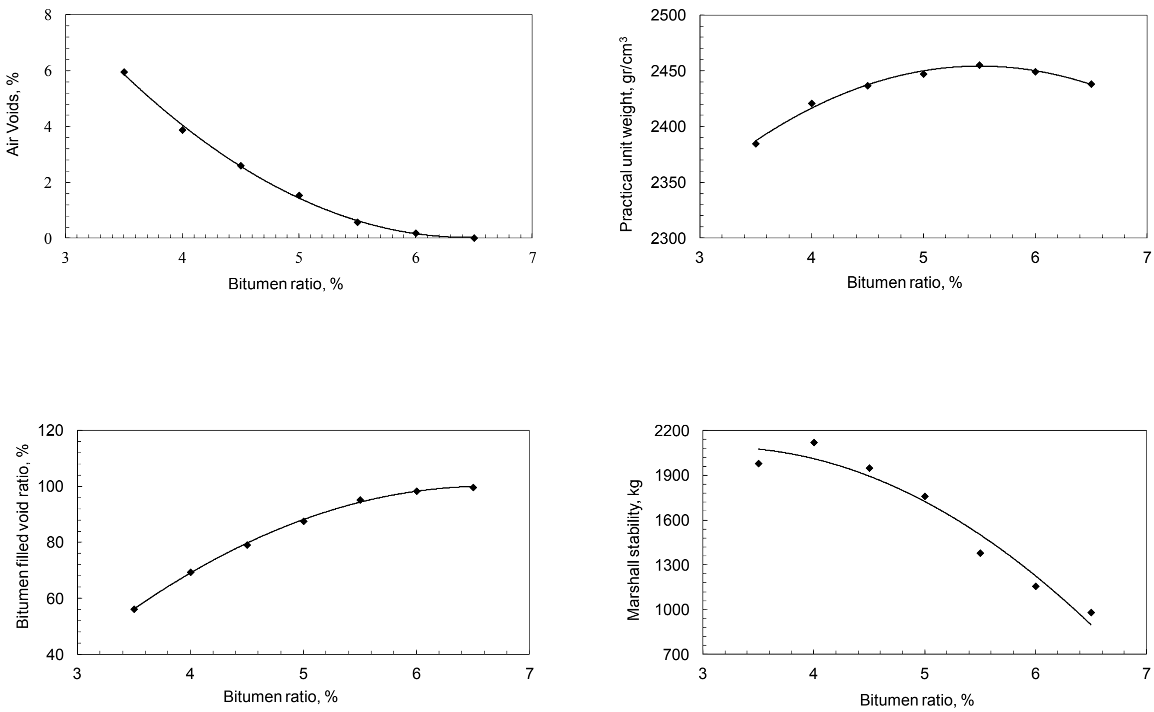


Fig 4. Marshall results of control samples

## 3. Results

Thermal stability of rubber modified asphalt mixtures with different rubber contents and sizes were investigated. Two different sizes of crump tire used namely, CMR-300 and SMR-400. The mix design was done based on the Marshall method and the optimum bitumen content was determined 4.4%. CMR-300 were prepared at a proportion of 10% and SMR-400 were prepared at a proportion of 15% by weight of bitumen. CMR-300 particles passes size smaller than #40 mesh and SMR-400 particle size #80 mesh.

No segregation occurs in the mixture since rubber particles dissolve and adhere to aggregates at high temperatures. During the production under high pressure, Regular crumb rubber increases its volume when heated which decreases the overall stability of asphalt concrete. However CMR-300 and SMR-400 prevent volume increase with its size of increase in volume which is one of the main reasons for thermal stability. A proper compaction can be achieved at 130-135°C for CMR-300 and SMR-400 mixes.

Asphalt concrete without additive and additive with CMR-300, SMR-400 have the same engineering characteristics in terms of Marshall Stability. However CMR-300 or SMR-400 added asphalt concrete provides specific benefits regarding its response under repeated loading. Thermal properties also provide important advantages, particularly on cold region paved roads by absorbing the heat energy from the sunlight.

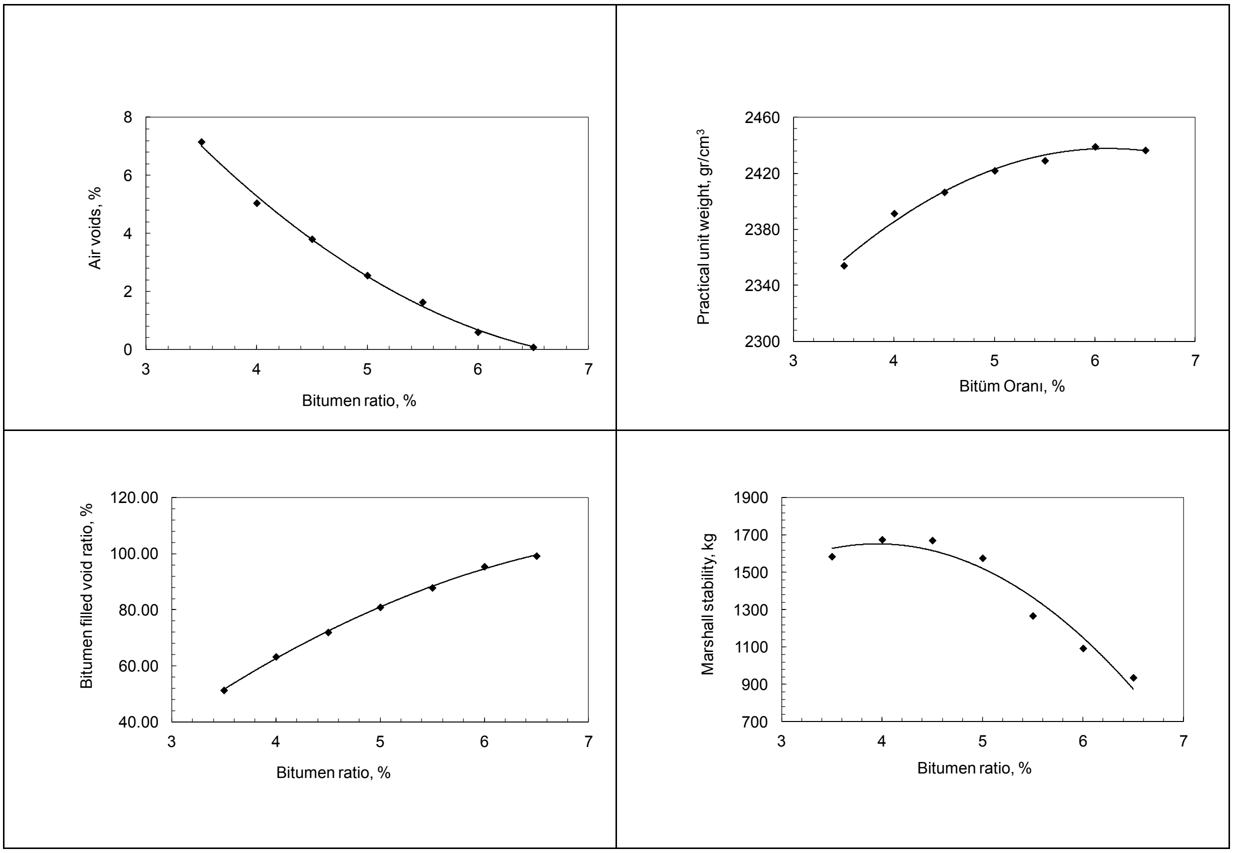


Fig 5. Marshall results of CMR-300

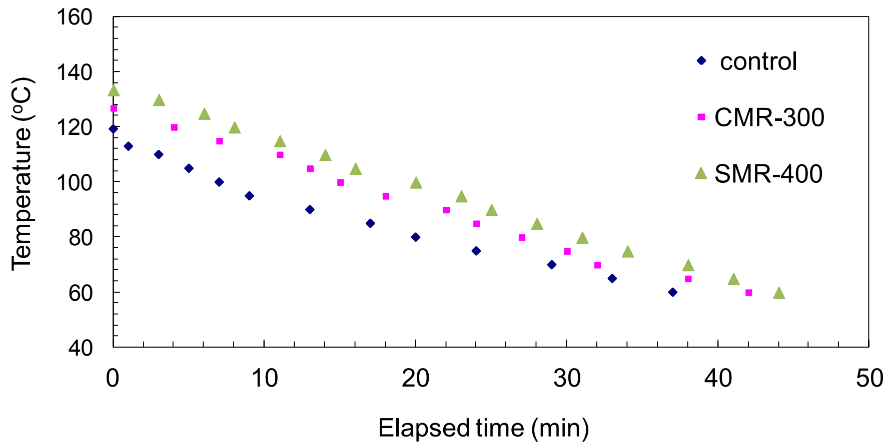


Fig. 6. Variation of temperature with respect to time (without aggregates)

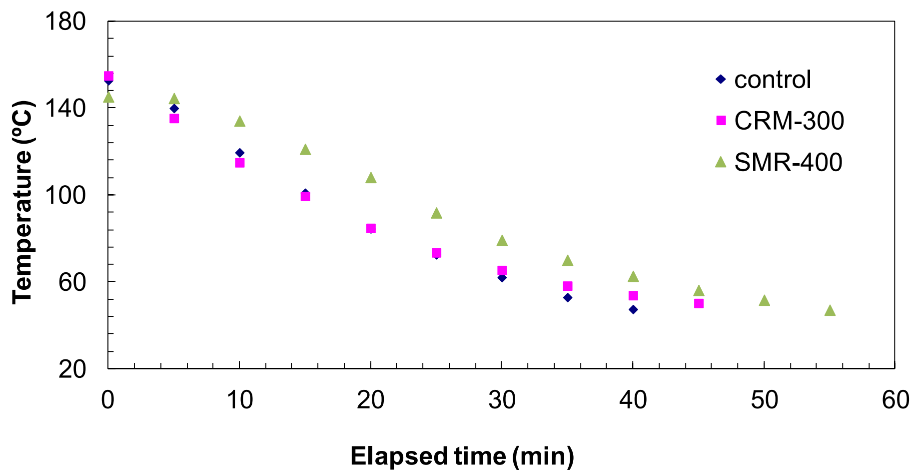


Fig. 7. Variation of temperature with respect to time (with aggregates)

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